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MAGNETIC FIELD RESTRAINTS FOR IMPs F and G

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Introduction

In order to insure the success of the magnetic field experiments on the IMP F&G spacecraft it is absolutely essential that contaminating magnetic fields associated with permanent and induced magnetization or circulating currents on the spacecraft be kept to an absolute minimum. Even with the most stringent efforts however it is clearly impossible to achieve the desired noise level of 0.25 gammas (= 2.5×10^{-6} Oerstad) at the magnetometer sensor unless it is located at a sufficiently remote distance from the spacecraft proper. At the present time this distance is approximately 82 inches to the fluxgate sensors and 65 inches to the Rb vapor magnetometer.

This report outlines in detail the acceptable magnetic testing procedures which are necessary for the success of the missions. Recommendations about fabrication of electronic structures and wiring of packages and solar cells are presented which minimize the magnetic field noise levels associated with these individual problem areas. Unfortunately there is no established and foolproof operating procedure which will insure the cleanliness of any package in the spacecraft. These recommendations present state of the art techniques which proved successful in solving the spacecraft magnetic field contamination problems on IMPA.

The magnetic field experimenter will be a participant with the project management in all discussions and decisions related to these magnetic field problem areas. As unique problems arise in eliminating the magnetic field contamination noise levels, close liaison between the magnetic field experimenter and appropriate personnel will be maintained. The recommendations included in this report are guide lines for all experimenters and contractors providing equipments for the prototype and the IMP F and G spacecraft.

The testing procedures outlined refer to mapping of the magnetic field noise levels of individual sub-assemblies. The testing of individual sub-assemblies, prior to integration of the units into the spacecraft, has proven extremely successful in detecting and allowing a reduction of contamination noise levels of separate packages while maintaining a reasonable spacecraft schedule.

In general, almost all packages have required a certain degree of re-work before they could be classified as magnetically acceptable. Upon completion of the mapping of individual sub-assemblies the testing of an integrated spacecraft is a simpler task in view of the necessity to monitor the magnetic field of the spacecraft rather than to investigate in detail its magnetic field and to localize the sources responsible for various contaminating effects.

1.0 Recommended Fabrication Procedures

In the design of various electronic circuits the designer may be forced to utilize components which in general can be magnetic due primarily to the presence of various iron and nickel compounds. Other materials can be magnetized, but in general the principal problems are associated with the presence of iron and nickel in various forms. Upon completion of the electronic circuit design every effort should be made to investigate the possibility of replacing all elements present by non-magnetic or minimally magnetic components.

1.1 Non-Magnetic Electronic Components

It is inadvisable to investigate the magnetic properties of components by exposing the individual items to the field of a magnet such as held in one's hand to determine if the item is magnetic. While this gross test does lead to some information, it is not sufficiently quantitative for determining how magnetic the item is. It is necessary to utilize a very sensitive magnetometer in an appropriate field-free environment to investigate the magnetic properties of these individual components.

In many instances it is impossible to obtain completely non-magnetic components. Certain of the magnetic materials are associated with the leads of the individual components. In these cases the mounting of various individual elements should be such as to minimize the length of the leads which are magnetic. Experience has shown most frequently that the caps and leads of certain types of transistors, and the "hot" lead of capacitors are magnetic. These leads should be trimmed so as to be less than 0.25" in length when mounted on the electronic cards.

The use of other than toroid structures for chokes, inductances or transformers is not recommended. While such non-toroid components may be magnetically clean with regard to permanent magnetization it is possible that the stray fields associated with the magnetically permeable material and their current loops as well as the solenoidal structure of the windings may lead to stray fields. (See Sec. 1.2.) Mu-metal cored toroids are recommended but powdered iron are not.

In certain sub-assemblies it is mandatory that the use of relays of various types be employed. Experience has shown that certain manufacturers produce relays which are very magnetic, while replacements can be obtained from the same or another supplier which are electrically and mechanically equivalent but are magnetically less contaminating. In such instances every effort should be made to replace such magnetic components with clean equivalents.

The utilization of shielding material is not recommended under any circumstance. Where possible all magnetic components such as relays which are magnetic should be placed in very close proximity to reduce the low order equivalent magnetic multipoles. The only recommended battery type which is non-magnetic are silver cadmium batteries available from Yardney Electric Company.

1.2 Non-magnetic Wiring of Components

Certain fabrication procedures referred to as cord-wood construction place electrical components in close proximity to obtain densely packed and geometrically small assemblies. In certain instances the interconnection between these units consist of welded wire material. At the present time, there are both magnetic and non-magnetic welded wire techniques for these interconnections. It is recommended that Alloy 180 be utilized in the welded wire work and in interconnections between solder boards. No nickel ribbon is to be used.

If welded wire modular construction is not employed but solder boards or other techniques are employed then in all instances all leads should be non-magnetic. Such items consisting of "rodar" or other nickel alloys are not recommended since they are quite magnetic.

In general the electrical current levels and the somewhat random location of individual components leads to cancellation of magnetic fields associated with wiring between individual modules. However, those leads carrying appreciable currents (tens of milliamperes) should be bi-filar wound (twisted pair) so as to self-cancel their magnetic effects. (See Sec. 1.4.)

1.3 Non-magnetic Structural Components

In the fabrication of the spacecraft it is important that all structural members, nuts, bolts, etc., be non-magnetic. In general aluminum and magnesium is clean although it is possible that the tools working the aluminum or magnesium structure contain magnetic chips and the material may be dirty due to inclusions of such material. All items should be checked for such magnetic properties. The use of stainless steel is not recommended unless a particular type is employed and care is exercised in the working of the material. Stainless steel 301 is acceptable material. In other instances checking of the proposed material should be made through utilization of the test procedures outlined in Section 2.0.

Caution must be exercised in the utilization of nickel plated brass for various types of interconnections in structural support. As previously pointed out the major source of magnetic contamination of the permanent magnetic type arises in the utilization of material containing iron or nickel. Such components are not recommended.

1.4 Dressing of Leads for Cancelling of Stray Fields within and between Sub-assemblies

In all instances leads between circulating positive and negative currents should be bi-filar wound, (twisted pair) so that all current loops are self-cancelling. Although the current levels are low in the sub-assemblies of the spacecraft, appreciable problems can arise if caution is not exercised in the lay-out of the electronics card so that there is cancellation of stray fields. It is not sufficient to place the cancelling leads on the top and bottom surfaces of the electronic cards to minimize stray fields. The only acceptable procedure is to utilize twisted pair cabling.

In wiring through plugs all leads clearly should be in as close geometrical proximity as possible. In certain instances it may be advisable to utilize coaxial connectors to allow the leads to enjoy the closest geometrical arrangement. The need for this consideration in the initial lay-out of the card can not be over emphasized to avoid considerable reworking following initial fabrication. All chokes and transformers must be toroid and carefully wired and designed to eliminate leakage fields.

1.5 Optimum Techniques for Wiring of Solar Cells and Power Leads

The wiring of the heavy power loads from the solar cell power supply and the battery to the converters and the various loads demands extreme care to assure cancellation of stray magnetic fields. All wiring of solar cells should be such as to yield cancellation of stray fields on a modular basis whereby all individual solar cell groups are back-wired with opposing current directions. Failure of separate modules will not distort the gross pattern of current flow in the solar cell surfaces if these practices are followed.

Wiring of batteries absolutely requires twisted pairs as does the wiring from the solar cell supplies to the converters and from the converters throughout the entire spacecraft. Extreme caution must be exercised to avoid circulating ground loops which are not cancelled. Individual package grounds twisted with the "hot" lead is the acceptable procedure for both power and telemetry sub-systems connections to the packages.

2.0 Magnetic Field Testing Procedures

2.1 Definition of Terms

It has been found that the problem of magnetic field contamination can become insurmountable if the individual problem areas are not well defined far in advance of spacecraft integration. Therefore, it is recommended that all sub-assemblies, packages and structural items which are logically distinct be tested for various types of magnetic field contamination according to the following procedures.

Magnetic field measurements shall be taken at 18 and 36 inches from the geometrical center of the individual sub-assemblies. The measurements in general require the cancellation of the earth's magnetic field to an accuracy of 1 gamma in a volume of approximately eight feet^3 so that the magnetic properties of the package can be investigated independent of the earth's magnetic field.

At the present time there are a limited number of magnetic test facilities which satisfy this requirement and also those groups which have the appropriate experience in mapping of magnetic fields. The final scheduling of these test procedures must be reached by the magnetic field experimenter, the spacecraft project manager and the spacecraft fabricator. Coilless methods of magnetic field mapping are not sufficiently sensitive nor accurate for the IMP's mission.

The magnetic testing procedure shall consist of pre-environmental test and post-environmental test magnetic field mapping in order to qualify all units for flight worthiness. Test of the initial, post-exposure, post-deperm, induced and stray magnetic fields shall be made on all sub-assemblies.

2.2 Initial Permanent Magnetic Field Mapping

Upon receipt of the sub-assembly the equivalent dipole magnetic field moment magnitude and direction shall be determined by mapping over a spherical surface the magnetic field of the sub-assembly at a distance of 18 inches and 36 inches from the geometrical center of the sub-assembly. The maximum allowable field is 8 gammas at 18 inches which is equivalent to 1 gamma at 36 inches if a dipole approximation to the package's magnetic field is appropriate. Measurements are to be made at both 18 inches and 36 inches to verify that this is indeed the case with the particular package under consideration. It is very possible that particular sub-assemblies will be so large as to preclude their consideration as an approximate dipole at distances of 18 inches. In these instances adequate mapping at 36 inches should be made to investigate the noise contamination to a level of 1 gamma and the dipole approximation checked at 48 inches.

2.3 Permanent Magnetic Field Mapping after 25 Gauss Exposure

The tests outlined in Section 2.1 are to be repeated after the package has been exposed to a 25 Gauss field directed along the initial permanent magnetic moment direction. The purpose of this exposure is to attempt to maximally magnetize the package and thereby reveal the degree to which the package could be magnetized during the conditions encountered in the launch maneuver as well as prior to launch. The level of 25 Gauss has been determined by investigation of magnetic fields associated with various dynamical test equipment. The maximum allowable field is 32 gammas at 18 inches which is equivalent to 4 gamma at 36 inches if a dipole approximation to the package's magnetic field is appropriate.

2.4 Permanent Magnetic Field Mapping after Deperming

After 25 Gauss exposure and the mapping of the maximum magnetic field a deperming process is followed whereby the permanent magnetic moment is destroyed by exposing the package to a steadily decreasing alternating current field. At the present time a level of 50 gauss and a 0.3 c/sec frequency is recommended although other programmed sequences are possible. Mapping is to be done as in Section 2.2. The maximum allowable field is 2 gammas at 18 inches which is equivalent to ~.25 gamma at 36 inches if a dipole approximation to the package's magnetic field is appropriate.

2.5 Stray Magnetic Fields due to Circulating Currents

Measurement of the magnetic fields associated with the circulating currents are to be made in a magnetic field-free region. In this case mapping at 18 inches to determine the maximum difference in the magnetic field associated with power-on/power-off conditions of the package is required. The appropriate power cabling to the individual packages should be bi-filar wound and cabled so as to minimize magnetic effects due to the excitation of the individual packages. The maximum allowable field is 4 gammas at 18 inches which is equivalent to 0.5 gamma at 36 inches if a dipole approximation to the package's magnetic field is appropriate.

2.6 Test Objectives

The design objectives for the entire integrated spacecraft when operating is that the total magnetic field disturbance for all sources shall not exceed 0.25 gamma as measured at the sensor. The above mappings are recommended to be carried out on a sensitivity scale such that fields of 1 gamma at 36 inches are accurately mapped. It is felt that mapping at 18 inches leading to a level equivalent to 8 gammas will guarantee this sensitivity in an appropriate coil facility. Such coil systems are presently in existence at Fredericksburg Magnetic Observatory, Corbin Virginia; Goddard Space Flight Center, Greenbelt, Maryland; and Jet Propulsion Laboratory, Malibu, California.

3.0 Magnetic Field Testing of Integrated Spacecraft

3.1 Permanent Magnetic Field Mapping of Integrated Spacecraft

In spite of the extensive test procedures described previously for the individual sub-assemblies, the allowable levels of the individual sub-assemblies are such that if circumstances are appropriate all magnetic field contamination effects can add vectorially and thereby exceed the design objectives. In order to check the entire spacecraft and map the magnetic field at the anticipated location of the sensor at the low level of one-fourth gamma it is recommended that a mapping be made of the entire spacecraft at a distance halfway between the geometrical center and the final position of the sensor. The mapping must take place in a non-magnetic coil facility which allows cancellation of the earth's magnetic field and also with a sensitive magnetometer whose accuracy and precision is well established by appropriate calibration procedures. The maximum net allowable field from all sources at this halfway distance is 2.0 gammas.

3.2 Operational Modes of Sub-assemblies and Telemetry and Data Systems

Due to the complex nature of the operation of the spacecraft it is important that all operational modes of the spacecraft be investigated following a mapping of the permanent magnetic field of the spacecraft. Both correct and failure modes of operation should be utilized to verify the "cleanliness" of the spacecraft harness, power distribution, and telemetry data system.

3.3 Operational Modes of Power System

All operational modes of the power system should be tested as in Sections 3.1 and 3.2. Artificial solar lamps should be used to illuminate the solar cells under various operating conditions.

4.0 Magnetic Test Criteria

Table I gives criteria for the acceptability of sub-assemblies. Table II gives criteria for the complete, integrated spacecraft.

Table I

Magnetic Test Criteria for IMP Subassemblies

Condition	Applied Field (gauss)	Maximum Magnetic Field Disturbance (Gamma)	
		18 inches	36 inches
1. Initial Perm.	0	8	1
2. Post 25 gauss exposure	0	32	4
3. Post 50 gauss deperm		2	0.25
4. Stray-"Power on" Vs. "Power off"	0	4	0.50

Table II

Magnetic Test Criteria for IMP Spacecraft

Condition	Applied Field (gauss)	Maximum Magnetic Field Disturbance (Gamma) 36 inches
1. Initial perm	0	1.0
2. Post 25 gauss exposure	0	10.0
3. Post 50 gauss de perm	0	1.0
4. Stray-"Power on" Vs. "Power off"	0	1.0